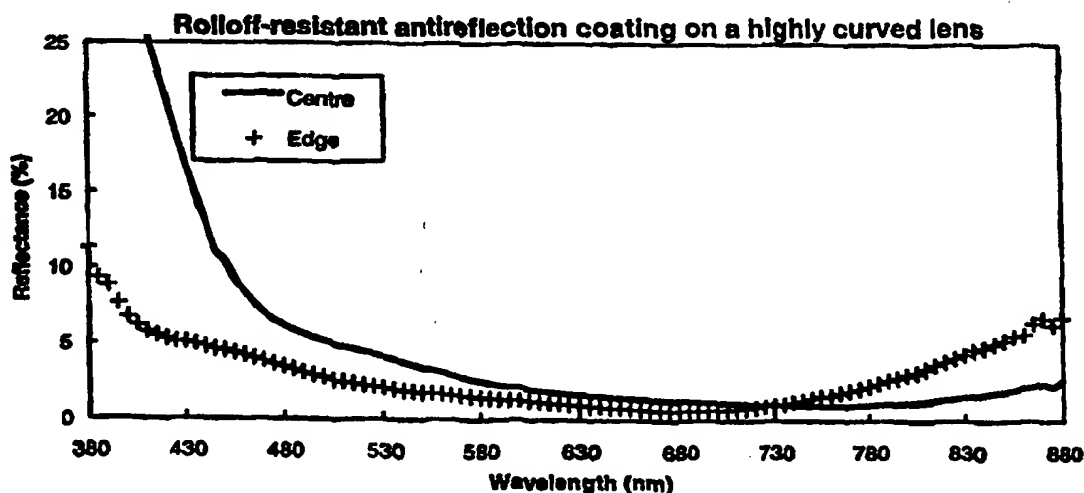




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**(54) Title:** COATED LENS EXHIBITING SUBSTANTIALLY BALANCED REFLECTANCE**(57) Abstract**

A coated optical lens includes a lens element and a coating on the surface of the lens element. The coating exhibits a substantially balanced reflectance from the centre to a radius proximate the edge of the lens element. The term "substantially balanced reflectance" means that where the thickness of the coating varies across the surface of the lens, the lightness, hue and chroma of the reflectance vary in a balanced manner such that variations in visual appearance are either imperceptible or generally acceptable to an observer. For example, variations in chromatic attributes, such as hue, from the centre to the edge of the lens may be balanced by a reduction in lightness from the centre to the edge. Preferably, the lens element includes a surface of high curvature upon which the balanced reflectance coating is deposited.

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## COATED LENS EXHIBITING SUBSTANTIALLY BALANCED REFLECTANCE

The present invention relates to optical articles bearing a coating which displays superior uniformity of reflection.

The optical articles according to the present invention are preferably employed in the preparation of articles such as optical lenses, including spectacle lenses, including sunglass lenses, visors, shields, glass sheets, protective screens, and the like.

Anti-reflection coatings are commonly deposited on ophthalmic and sunglass lenses in order to minimise spurious reflections, which both detract from the wearer's vision and are also cosmetically displeasing. These coatings commonly consist of multilayer, dielectric films of thicknesses chosen so that interference effects cause destructive cancellation of reflections over most of the visible spectrum.

A coating that is not anti-reflective and that changes the reflectance of the lens can be described as a "mirror" coating. Such mirror coatings are often used in the manufacture of sunglass lenses, to produce fashionable lens colours.

When mirror and anti-reflection coatings are deposited on curved substrates (such as ophthalmic lenses), regardless of the deposition method used (eg. evaporative, sputtered, etc.) geometrical factors result in the coating thickness being non-uniform and varying systematically over the surface of the lens. The coating thickness is typically greatest where the surface of the substrate is most normal to the incident flux of particles, and thinner where the surface faces the flux at an angle. For ophthalmic lenses, which are normally mounted with their centres facing the particle source, this means a coating that is thickest in the centre and that becomes thinner towards the edge of the lens element. This effect becomes more pronounced as the lens becomes more highly curved.

The coating thickness variations manifest themselves as visible variations in the reflectance from the coated lens. The colour (specified by "lightness", "hue"

and "chroma") of the residual reflection changes from the centre to the edge of the lens, an effect referred to as "colour rolloff." For lenses of normal curvature, the colour rolloff is barely noticeable and cosmetically, the lenses are considered to be acceptable. However, for very highly curved lenses, the colour rolloff is particularly noticeable and is generally considered to be unsatisfactory.

One method proposed in the prior art to reduce colour rolloff is to mount the substrate on a "planetary rotation" stage, which spins the lens about its own axis at the same time that it rotates about another central axis. The result of the complex substrate motion in the deposition chamber is that the flux of coating material is more evenly distributed over the surface of the lens, resulting in a coating that is more uniform over the substrate than would otherwise be the case. Planetary rotation is not the only option - any substrate motion at all will tend to reduce coating thickness non-uniformities. Unfortunately, implementing such substrate movement in the deposition chamber necessary involves mechanical complexity and a likely decrease in the total number of substrates that can be coated simultaneously in the apparatus, which is a severe disadvantage in a commercial production process.

It would accordingly be a significant advance in the art if ophthalmic lenses could be provided with a coating or coatings of general applicability which could reduce the phenomenon of "colour rolloff", but without the need for "planetary rotation" apparatus.

Accordingly, it is an object of the present invention to overcome, or at least alleviate, one or more of the difficulties or deficiencies related to the prior art.

Accordingly, in a first aspect of the present invention there is provided a coated optical lens including

a lens element; and

a coating on a surface of the lens element exhibiting a substantially balanced reflectance from the centre to a radius proximate the edge of the lens element.

The lens element may preferably include a surface of high curvature, upon which the balanced reflectance coating is deposited. By the term "surface of high curvature", we mean a surface having a base curve approximately 6 Dioptres (D) or greater, preferably 6 D to 20 D, more preferably approximately 8 D to 16 D.

- 5        The lens element may be either optically clear or tinted (light absorbing), such as a sunglass lens, ophthalmic lens element, visor or the like.

By the term "ophthalmic lens element", as used herein, we mean all forms of individual refractive optical bodies employed in the ophthalmic arts, including, but not limited to, lenses, lens wafers and semi-finished lens blanks requiring  
10 further finishing to a particular patient's prescription.

The visual appearance of the coated optical lens in reflected light can be quantified by measuring its reflectance spectrum in a spectrophotometer. It is well known that the reflectance of thin film coatings tends to vary with the angle of the incident light. When we speak of the reflectance from the lens we imply the  
15 reflectance of light incident at angles of 0 to approximately 30 degrees to the normal to the surface of the lens, as would typically be the case for the reflected light seen by an observer standing directly in front of a person wearing the coated lenses as spectacles. This spectral information may be reduced to three colour coordinates - a "lightness" corresponding primarily to the luminous intensity of the  
20 reflected light, and two chromatic attributes, "hue" and "chroma", corresponding to the general colour (e.g. "red", "blue", "green" etc.) and its vividness. ("The Measurement of Appearance", 2<sup>nd</sup> ed., R.S. Hunter and R.W. Harold, Wiley, New York, 1987).

By the term "substantially balanced reflectance" we mean that where the  
25 thickness of the coating varies across the surface of the lens, the lightness, hue and chroma of the reflectance vary in a balanced manner such that variations in visual appearance are either imperceptible or generally acceptable to an observer. For example, variations in chromatic attributes, such as hue, from the centre to the edge of the lens may be balanced by a reduction in lightness from the centre to  
30 the edge.

Perceived variations in appearance may be quantified by calculating "CMC colour differences," as developed by the Colour Measurement Committee of the Society of Dyers and Colourists. A CMC colour variation of  $\Delta E_{\text{CMC}(2:1)}=1$  is the limit of acceptability for textiles. Applicants have found that this is too stringent a tolerance for anti-reflection or mirror coated lenses in the ophthalmic industry. Variations between anti-reflection coated lenses of approximately 3 or less are acceptable and Applicants have observed that colour differences of up to 3-11 may exist across a lens that has an acceptably uniform appearance. Variations of up to 20 may exist in lenses that are visibly non-uniform in colour, yet that are still acceptable in appearance.

The normal incidence reflectance spectrum of a highly curved (16 dioptre) lens coated with a typical commercial anti-reflection coating is shown in Figure 1.

The reflectance of light of essentially normal incidence measured at the centre of the lens element is low in the visible spectrum (roughly 380-780 nm), but is significantly greater for longer wavelengths. Toward the edge of the lens element (eg. at a radius of 20 mm from the centre), the total coating thickness may be reduced to 80% of the thickness at the centre of the lens. This is due to the curvature of the lens and the geometry of the deposition system as described above. As shown in the figure, the spectrum shifts to the left relative to the spectrum from the centre of the lens. This is a well-known phenomenon to those familiar with the art and theory of thin films. As a consequence, the higher reflectance "red tail" seen in Figure 1 moves further into the region of spectral sensitivity of the human eye and causes the appearance of the lens to redden toward the edges. The CMC colour difference (for CIE illuminant C) between the centre of the lens and at the radius of 20 mm is  $\Delta E_{\text{CMC}(2:1)}=27$ . The lens displays substantial colour roll-off, changing from faint green in the centre to bright red/orange at the edges and is unacceptable.

In contrast, the balanced reflectance coating according to the present invention has a substantially more uniform appearance from the centre to the edge of the lens element (see Figure 2 below).

Figure 2 compares the reflectance spectra at the centre and at a radial distance of 20 mm from the centre on a 16 dioptre lens now coated with the roll-off-resistant coating. In contrast to the previous standard anti-reflection coating, this coating (at the centre of the lens) exhibits substantially lower photopic reflectance at longer wavelengths. Indeed, it is anti-reflective beyond 880 nm. When the coating thickness reduces away from the centre of the lens and the reflectance spectrum shifts to the left, relatively little intensity is introduced in the red region of the spectrum. The CMC colour difference (for CIE illuminant C) between the centre of the lens and at the radius of 20 mm is  $\Delta E_{CMC(2:1)}=10$ . The lens displays relatively little colour roll-off. The lens changes from light blue in the centre to pale blue/purple at the edges and is quite acceptable.

This may be achieved, inter alia, by providing a balanced reflectance coating for a lens element which, in use, exhibits a substantially constant low photopic reflectance in the red-to-infra-red wavelength range of approximately 620 to 880 nm proximate the centre of the lens element.

Preferably, the photopic reflectance is less than approximately 3%. The reflectance is preferably low where the eye is most sensitive, in the region of approximately 550 nm.

The low reflectance in the near infra-red spectrum is clearly an important characteristic of the balanced reflectance coating, but for certain coloured coatings this alone may not ensure that it displays acceptable colour roll-off eg. on a highly curved lens. For example, if the coating displays a red colour in the centre of the lens, even if the reflectance in the near infra-red is low, the colour will roll through yellow and green as the thickness rolls off from centre to edge of the lens. If a uniform hue is desired the roll-off will not be acceptable. If, however, a multicoloured lens, which is still functionally anti-reflective as its hue changes is the desired result, then the lens will exhibit acceptable colour roll-off, because the colour roll-off is balanced by luminous reflectance roll-off (as opposed to hue) which is acceptable.

The balanced reflectance coating is not restricted to functioning as an anti-

reflection coating. The balance of reflectance coating may alternatively or in addition function as a light absorbing, or tint coating, in which case it may also have an asymmetric reflectance, such that from the wearer's side of the lens element the coating is anti-reflective. The balanced reflectance coating may also  
5 function as a reflective or mirror coating.

The balanced reflectance coating may exhibit a substantially constant low photopic reflectance in the wavelength range of approximately 620 to 880 nm, the photopic reflectance preferably being less than approximately 1.5%.

The balanced reflectance coating may, for example, exhibit a reflected  
10 colour difference from the centre to a radius of approximately 20 mm on the lens surface of less than approximately 11 CMC colour difference units.

Alternatively, the coating may exhibit a reflected colour difference ( $\Delta E$ ) from the centre to a radius of approximately 20 mm on the lens surface of greater than approximately 11 CMC colour difference units, the colour difference being  
15 balanced by a complementary reduction in luminous intensity.

More preferably the coating exhibits a reflected colour difference ( $\Delta E$ ) of from approximately 11 to 20 CMC colour difference units.

In this embodiment the coating is preferably a multicoloured, anti-reflective coating.

20 In accordance with the present invention, one or both surfaces of an optical lens element may be coated with the balanced reflectance coating.

In a preferred aspect, the lens element may be of generally ovaline shape and is located on the surface of a sphere whose radius of curvature corresponds to 11 D or above, a toroid where the horizontal radius of curvature corresponds to  
25 11 D or above, or a surface where the radius of curvature changes across at least one section of the lens aperture.



The lens element may be of the type described in International Patent Application PCT/AU98/00872 "Spectacle Frames" to Applicants, the entire disclosure of which is incorporated herein by reference; or in Australian Provisional Patent Application PP4748 "Optical Lens" to Applicants, the entire  
5 disclosure of which is incorporated herein by reference.

It will be appreciated that while the balanced reflectance coating can be beneficially applied to a highly curved lens, its use is not restricted to such an application. For instance, the balanced reflectance coating can be applied in a situation where the deposition process is imperfectly controlled. In such a case,  
10 variations in coating thickness caused by the deposition process (rather than the high curvature of the lenses being coated) are less visible, by virtue of the optical properties of the balanced reflectance coating.

Where the lens element is an ophthalmic lens element, the ophthalmic lenses may be formed from a variety of different lens materials, and particularly  
15 from a number of different polymeric plastic resins. A common ophthalmic lens material is diethylene glycol bis (allyl carbonate) or CR39 (PPG Industries). Lens materials with higher refractive indices are now growing in popularity. Other examples of lens materials that may be suitable for use with the invention include other acrylics, other allylics, styrenics, polycarbonates, vinyls, polyesters and the  
20 like.

In a preferred aspect, the balanced reflectance coating may be a multi-layer coating. The balanced reflectance coating may include a plurality of layers, the thickness and/or number of which being selected to reduce the phenomenon of "colour rolloff". The balanced reflectance coating may further provide an  
25 interference effect, e.g. an anti-reflective or mirror effect.

More preferably the balanced reflectance coating includes a plurality of layers, wherein the thickness and/or number of the respective layers are selected to provide a substantially balanced reflectance in response to visual effects generated by variations in thickness of the coating in use, for example, as may  
30 occur when applied to a surface of a lens of high curvature.

In this embodiment, the coating may include a plurality of layers of differing refractive index wherein the thickness and/or number of the respective layers are selected to balance the variation of any combination of reflectance lightness, hue and chroma.

5           More preferably, the balanced reflectance coating exhibits a substantially constant low photopic reflectance in the red-to-infra-red wavelength range of approximately 620 to 880 nm, the photopic reflectance preferably being less than approximately 3%. The reflectance is preferably low where the eye is most sensitive, in the region of approximately 550 nm, so that the coating has an anti-  
10   reflective character.

The number and/or thickness of the layers may be selected utilising suitable computer software, adapted to minimise the variation of any combination of reflected lightness, hue or chroma accompanying variations in coating thickness.

15           In addition other desired coating properties may be provided at the same time.

The layers of differing refractive index may be formed from any suitable material. The low and high refractive index layers may be formed of a dielectric material. Preferably the dielectric layers may be formed from metal oxides,  
20   fluorides or nitrides and diamond-like carbon. Preferably the dielectric material is selected from one or more of  $\text{Al}_2\text{O}_3$ ,  $\text{BaTiO}_3$ ,  $\text{Bi}_2\text{O}_3$ ,  $\text{B}_2\text{O}_3$ ,  $\text{CeO}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{Ga}_2\text{O}_3$ ,  $\text{GeO}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{HfO}_2$ ,  $\text{In}_2\text{O}_3$ , Indium-tin oxide,  $\text{La}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{Nd}_2\text{O}_3$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{Pr}_2\text{O}_3$ ,  $\text{Sb}_2\text{O}_3$ ,  $\text{Sc}_2\text{O}_3$ ,  $\text{SiO}$ ,  $\text{SiO}_2$ ,  $\text{SnO}_2$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{TiO}$ ,  $\text{TiO}_2$ ,  $\text{TiO}_3$ ,  $\text{WO}_3$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{Yb}_2\text{O}_3$ ,  $\text{ZnO}$ ,  $\text{ZrO}_2$ ,  $\text{AlF}_3$ ,  $\text{BaF}_2$ ,  $\text{CaF}_2$ ,  $\text{CdF}_2$ ,  $\text{CeF}_3$ ,  $\text{HfF}_4$ ,  $\text{LaF}_3$ ,  $\text{LiF}$ ,  $\text{MgF}_2$ ,  $\text{NaF}$ ,  $\text{Na}_3\text{AlF}_6$ ,  $\text{Na}_5\text{Al}_3\text{F}_{14}$ ,  $\text{NdF}_3$ ,  $\text{PbF}_2$ ,  
25    $\text{PrF}_3$ ,  $\text{SrF}_2$ ,  $\text{ThF}_4$ ,  $\text{ZrF}_4$ ,  $\text{Si}_3\text{N}_4$ ,  $\text{AlN}$ .

Optionally the dielectric materials may include standard dopants, for example other materials or metal compounds. See for example United States Patent 3,914,516 "Balzers".

Alternatively, the layers of differing refractive index may be formed from layers of polymeric materials having varying refractive index. Such polymeric materials may be produced utilising plasma enhanced chemical vapour deposition (PECVD) techniques. See for example European patent EP 0916683 "Clariant International Ltd".

A silica ( $\text{SiO}_2$ ) or magnesium fluoride ( $\text{MgF}_2$ ) material is preferred for the lower index layers.

The higher refractive index layer may exhibit a refractive index of approximately 2.0 or greater. A titanium oxide ( $\text{TiO}_2$ ) or combination of titanium and praseodymium oxide ( $\text{TiO}_2 + \text{Pr}_2\text{O}_3$ ) is preferred for the higher index layer(s). Such a combination may have a refractive index at 500 nm of approximately 2.15.

In a preferred form, the balanced reflectance coating may include a total of 2 to 6 alternating layers of differing refractive index, preferably 4 to 6 alternating layers.

Alternatively, the balanced reflectance coating may be formed of dielectric and metallic layers. Preferably the dielectric layers may be formed from metal oxides, fluorides or nitrides and diamond-like carbon. Preferably the dielectric material is selected from one or more of  $\text{Al}_2\text{O}_3$ ,  $\text{BaTiO}_3$ ,  $\text{Bi}_2\text{O}_3$ ,  $\text{B}_2\text{O}_3$ ,  $\text{CeO}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{Ga}_2\text{O}_3$ ,  $\text{GeO}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{HfO}_2$ ,  $\text{In}_2\text{O}_3$ , Indium-tin oxide,  $\text{La}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{Nd}_2\text{O}_3$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{Pr}_2\text{O}_3$ ,  $\text{Sb}_2\text{O}_3$ ,  $\text{Sc}_2\text{O}_3$ ,  $\text{SiO}$ ,  $\text{SiO}_2$ ,  $\text{SnO}_2$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{TiO}$ ,  $\text{TiO}_2$ ,  $\text{TiO}_3$ ,  $\text{WO}_3$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{Yb}_2\text{O}_3$ ,  $\text{ZnO}$ ,  $\text{ZrO}_2$ ,  $\text{AlF}_3$ ,  $\text{BaF}_2$ ,  $\text{CaF}_2$ ,  $\text{CdF}_2$ ,  $\text{CeF}_3$ ,  $\text{HfF}_4$ ,  $\text{LaF}_3$ ,  $\text{LiF}$ ,  $\text{MgF}_2$ ,  $\text{NaF}$ ,  $\text{Na}_3\text{AlF}_6$ ,  $\text{Na}_5\text{Al}_3\text{F}_{14}$ ,  $\text{NdF}_3$ ,  $\text{PbF}_2$ ,  $\text{PrF}_3$ ,  $\text{SrF}_2$ ,  $\text{ThF}_4$ ,  $\text{ZrF}_4$ ,  $\text{Si}_3\text{N}_4$ ,  $\text{AlN}$ . Preferably the metallic material is selected from the metals, metal oxides or nitrides of one or more of Aluminium (Al), Chromium (Cr), Niobium (Nb), Nickel (Ni), Palladium (Pd), Tin (Sn), Tantalum (Ta), Titanium (Ti), Tungsten (W) or Zirconium (Zr).

A silica ( $\text{SiO}_2$ ) or magnesium fluoride ( $\text{MgF}_2$ ) material is preferred for the low index layers.

Chromium (Cr) or Niobium (Nb) is preferred for the metallic layers.

The optical lens according to the present invention may further include one or more additional coatings. Accordingly in a further aspect of the present invention there is provided a multi-coated optical lens including

- a lens element;
- 5 a coating on a surface of the lens element exhibiting a substantially balanced reflectance from the centre to a radius proximate the edge of the lens element; and

one or more secondary coatings which provide a desirable optical and/or chemical and/or mechanical property to the optical article.

- 10 Preferably, the lens element includes a surface of high curvature upon which the balanced reflectance coating is deposited.

More preferably, in use, the coating exhibits a reflected colour difference from the centre to a radius of approximately 20 mm on the lens surface of less than approximately 11 CMC colour difference units or less.

- 15 Alternatively, the coating exhibits a reflected colour difference ( $\Delta E$ ) from the centre to a radius of approximately 20 mm on the lens surface of greater than approximately 11 CMC colour difference units, the colour difference being balanced by a complementary reduction in luminous intensity

- 20 The secondary coating(s) may overlay or underlay the balanced reflectance coating or be applied to a second surface of the lens element.

- The secondary coating(s) may be of any suitable type. The secondary coating(s) may be selected from one or more of an anti-reflective, abrasion resistant, impact-resistant or hydrophobic coating. An abrasion-resistant coating is preferred. The combination of an abrasion resistant coating and an anti-reflective coating is particularly preferred.
- 25

Applicants have further noted that, where the balanced reflectance coating is applied to both surfaces of an ophthalmic lens element it is possible to improve optical performance, including colour uniformity, on highly curved substrates even

further by balancing the colour variations between the two surfaces. It may further be possible to reduce or eliminate other optical aberrations, such as "ghost images" which may be generated by reflective coatings.

Accordingly, in a preferred aspect of the present invention, there is provided

5 a multi-coated optical lens including

- a lens element;
- a first coating on the front surface of the lens element; and
- a secondary coating on the back surface of the lens element; the first and

second coatings in combination exhibiting a substantially balanced reflectance

10 from the centre to a radius proximate the edge of the lens element.

The first coating on the front surface may be similar to the balanced reflectance coatings described above.

The secondary coating may function to reduce optical aberrations, such as "ghost images". The secondary coating exhibits a difference in lightness or hue

15 relative to the first coating, for example a reduction in lightness.

Alternatively, the secondary coating may exhibit a reflectance peak which is spectrally displaced with respect to the reflectance peak of the first coating. The secondary coating consequently exhibits a different hue to the first coating.

In a further preferred aspect of the present invention, one or both surfaces

20 of the optical article may be subjected to a surface treatment to improve bondability and/or compatibility of the balanced reflectance and/or secondary coating. The surface treatment may be selected from one or more of the group consisting of plasma discharge, corona discharge, glow discharge, ionising radiation, UV radiation, flame treatment and laser, preferably excimer laser

25 treatment. A plasma discharge treatment is preferred. The surface treatment, alternatively or in addition, may include incorporating another bonding layer, for example a layer including a metal or metal compound selected from the group consisting of one or more of Chromium, Nickel, Tin, Palladium, Silicon, and/or oxides thereof.

The optical article may be a sunglass lens of the wrap-around or visor type, for example of the type described in International Patent Application PCT/AU97/00188 "Improved Single Vision Lens" to Applicants, the entire disclosure of which is incorporated herein by reference.

5 In a further aspect of the present invention, there is provided a method for preparing a coated optical lens, which method includes providing

10 a lens element,  
a coating exhibiting a substantially balanced reflectance from the  
centre to a radius proximate the edge of the lens element; and  
depositing the coating on a surface of the lens element.

Preferably the lens element includes a surface of high curvature upon which the balanced reflectance coating is deposited. More preferably the balanced reflectance coating is applied to both surfaces of the lens element.

15 According to the present invention it has been found that, following the method mentioned above, it is possible to achieve a relatively thin, balanced reflectance coating with consequent advantages in both optical and mechanical properties.

20 Preferably the method further includes providing

a lens element,  
a high refractive index material, and  
a low refractive index material;

25 depositing overlapping layers of high and low refractive index material on a surface of the optical lens element, wherein the thickness and/or number of the respective layers are selected to balance the variation of any combination of reflected lightness (luminous intensity), hue and chroma.

The balanced reflectance coating may further provide a desired interference effect, preferably an anti-reflective effect or mirror effect.

In a preferred aspect the high and low refractive index materials, preferably  $\text{TiO}_2$ ,  $\text{Pr}_2\text{O}_3/\text{TiO}_2$  and  $\text{SiO}_2$ , are deposited as alternating layers.

Alternatively, the method may include providing

5 a lens element;

a dielectric material selected from one or more of  $\text{Al}_2\text{O}_3$ ,  $\text{BaTiO}_3$ ,  $\text{Bi}_2\text{O}_3$ ,  $\text{B}_2\text{O}_3$ ,  $\text{CeO}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{Ga}_2\text{O}_3$ ,  $\text{GeO}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{HfO}_2$ ,  $\text{In}_2\text{O}_3$ , Indium-tin oxide,  $\text{La}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{Nd}_2\text{O}_3$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{Pr}_2\text{O}_3$ ,  $\text{Sb}_2\text{O}_3$ ,  $\text{Sc}_2\text{O}_3$ ,  $\text{SiO}$ ,  $\text{SiO}_2$ ,  $\text{SnO}_2$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{TiO}$ ,  $\text{TiO}_2$ ,  $\text{TiO}_3$ ,  $\text{WO}_3$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{Yb}_2\text{O}_3$ ,  $\text{ZnO}$ ,  $\text{ZrO}_2$ ,  $\text{AlF}_3$ ,  $\text{BaF}_2$ ,  $\text{CaF}_2$ ,  $\text{CdF}_2$ ,  $\text{CeF}_3$ ,  $\text{HfF}_4$ ,  $\text{LaF}_3$ ,  $\text{LiF}$ ,  $\text{MgF}_2$ ,  $\text{NaF}$ ,  $\text{Na}_3\text{AlF}_6$ ,  $\text{Na}_5\text{Al}_3\text{F}_{14}$ ,  $\text{NdF}_3$ ,  $\text{PbF}_2$ ,  $\text{PrF}_3$ ,  $\text{SrF}_2$ ,  $\text{ThF}_4$ ,  $\text{ZrF}_4$ ,  $\text{Si}_3\text{N}_4$ ,  $\text{AlN}$ , or diamond-like carbon; and

a metallic material selected from the metals, metal oxides or nitrides of one or more of Aluminium (Al), Chromium (Cr), Niobium (Nb), Nickel (Ni), Palladium (Pd), Tin (Sn), Tantalum (Ta), Titanium (Ti), Tungsten (W) or Zirconium (Zr)

15 depositing overlapping layers of dielectric and metallic material on a surface of the optical lens element, the number and/or thickness of the respective layers being selected to balance the variation of any combination of reflected lightness, hue and chroma.

20 Preferably, the dielectric material is magnesium fluoride ( $\text{MgF}_2$ ) or silica ( $\text{SiO}_2$ ); and the metallic material is Niobium (Nb) or Chromium (Cr).

The deposition step may be a vacuum deposition step. The deposition step may be conducted in a coating apparatus. A box coater or sputter coater may be used.

25 The balanced reflectance coating may preferably be formed on the surfaces of the substrate according to the process and the box coaters as described in the Italian Patent No. 1.244.374 the entire disclosure of which is incorporated herein by reference.

In accordance with said method, the various layers of the balanced

reflectance coating may be deposited in subsequent steps utilising a vacuum evaporation technique and exposing the growing layers to a bombardment of a beam of ions of inert gas.

Moreover, in accordance with the preferred method, the deposition of the  
5 layers may be achieved at a low temperature (generally below 80°C), using an ion beam having a medium intensity (meaning the average number of ions that reach the substrate) included between approximately 30 and 100  $\mu\text{A}/\text{cm}^2$  and the energy included between approximately 50 and 100 eV.

Further characteristics and advantages of the present invention will be  
10 apparent from the following description of drawings and examples of embodiments of the present invention, given as indicative but not restrictive.

In the figures:

Figure 1 illustrates a measured reflectance spectrum (for light at normal incidence) of a lens coated on both sides with a known multilayer, anti-reflection  
15 coating.

Figure 2 illustrates a measured reflectance spectrum (for light at normal incidence) of a lens coated on both sides with a multilayer, anti-reflection coating corresponding to the present invention.

Figure 3 compares the typical reflectance spectra measured at the centre  
20 and at a radius of 20 mm on a 16 diopetre polycarbonate lens coated on both sides with the balanced reflectance coating.

Figure 4 illustrates the calculated reflectance spectrum for a CR39 lens coated on both sides with the balanced reflectance coating, as well as the reflectance spectrum when the coating thickness is reduced by 20%.

25 Figure 5 illustrates the corresponding calculated reflectance spectra for tinted CR39 lenses coated on the front surface with the balanced reflectance



coatings.

## EXAMPLE 1

### Standard anti-reflection coating

Figure 1 illustrates a measured reflectance spectrum (for light at normal incidence) of a 16 dioptre polycarbonate lens coated on both sides with an abrasion-resistant coating and a typical commercial multilayer, anti-reflection coating.

The reflectance at the centre of the lens is low in the visible spectrum (roughly 380-780 nm), but is significantly greater for longer wavelengths. Toward the edge (at a radius of 20 mm), the total coating thickness is reduced to 80% of the thickness at the centre of the lens. This is due to the curvature of the lens and the geometry of the deposition system, a Satis 1200 evaporative box coater. As shown in the figure, the spectrum shifts to the left relative to the spectrum from the centre of the lens. This is a well-known phenomenon to those familiar with the art and theory of thin films. As a consequence, the higher reflectance "red tail" seen in Figure 1 moves further into the region of spectral sensitivity of the human eye and causes the appearance of the lens to redden toward the edges. The CMC colour difference (for CIE illuminant C) between the centre of the lens and at the radius of 20 mm is  $\Delta E_{CMC(2:1)}=27$ . The lens displays substantial colour roll-off, changing from faint green in the centre to bright red/orange at the edges and is unacceptable.

**TABLE 1**  
**Standard commercial anti-reflection coating**

Layer	Thickness (nm)
Polycarbonate substrate	
SiO <sub>2</sub>	173
Pr <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub> (n(500 nm) =2.05)	23.4
SiO <sub>2</sub>	18.7
Pr <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub> (n(500 nm) =2.05)	93.2
SiO <sub>2</sub>	82.6
Hydrophobic	10

## EXAMPLE 2

### 5      **Balanced reflectance anti-reflection coating with low variation in hue**

Table 2 shows the optical design for an anti-reflection coating whose reflected colour, particularly its hue, is robust to colour roll-off when its thickness varies.

Figure 2 compares the reflectance spectra measured at the centre and at a  
 10 radius of 20 mm on a 16 dioptre CR39 lens coated on both sides with the  
 balanced reflectance coating. In contrast to the standard anti-reflection coating of  
 the previous example, this coating (at the centre of the lens) exhibits substantially  
 lower photopic reflectance at longer wavelengths. Indeed, it is anti-reflective  
 beyond 880 nm. When the coating thickness reduces away from the centre of the  
 15 lens and the reflectance spectrum shifts to the left, relatively little intensity is  
 introduced in the red region of the spectrum. The CMC colour difference (for CIE  
 illuminant C) between the centre of the lens and at the radius of 20 mm is  
 $\Delta E_{CMC(2:1)}=10$ .

The lens displays relatively little colour roll-off, particularly in its hue. The  
 20 lens changes from light blue ( $h^* = 292^\circ$ ) in the centre to pale blue/purple ( $h^* =$

281°) at the radius of 20 mm. The luminous intensity of the reflection concurrently reduces from 3.4% to 1.8%.

The result is a coating that demonstrates substantially improved colour uniformity on highly curved substrates, without the requirement for additional substrate motion during deposition.

**TABLE 2**

**Optical design for a balanced reflectance anti-reflection coating**

Layer	Thickness (nm)
Hard resin substrate	
TiO <sub>2</sub> (n(500 nm) =2.15)	15.9
SiO <sub>2</sub>	32.5
TiO <sub>2</sub> (n(500 nm) =2.15)	147
SiO <sub>2</sub>	102

### EXAMPLE 3

#### 10 **Balanced reflectance anti-reflection coating with low variation in lightness**

Table 3 shows the optical design for another anti-reflection coating whose reflected colour is robust to colour roll-off when its thickness varies.

Figure 3 compares the typical reflectance spectra measured at the centre and at a radius of 20 mm on a 16 diopetre polycarbonate lens coated on both sides with the roll-off-resistant coating. (The spectra are the averages of measurements taken on 27 different coated lenses.) The CMC colour difference (for CIE illuminant C) between the centre of the lens and at the radius of 20 mm is  $\Delta E_{CMC(2:1)}=16$ .

The lens displays relatively little colour roll-off, particularly in its luminance.  
 20 The lens changes from pale green ( $h^* = 224^\circ$ ) in the centre to pale blue/purple ( $h^*$

= 289°) at the radius of 20 mm. While the change in hue is noticeable, it is not unpleasant and is judged to be acceptable because the luminous intensity of the reflection concurrently reduces from 1.8% to only 1.2%.

**TABLE 3**

**Optical design for a balanced reflectance anti-reflection coating**

Layer	Thickness (nm)
Polycarbonate substrate	
Abrasion-resistant coating	2500
SiO <sub>2</sub>	18
Pr <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub> (n(500 nm) =2.05)	17.9
SiO <sub>2</sub>	36.7
Pr <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub> (n(500 nm) =2.05)	140.2
SiO <sub>2</sub>	91.8

**EXAMPLE 4****Balanced reflectance anti-reflection coating with high variation in hue**

Table 4 shows the optical design for another anti-reflection coating whose reflected lightness is robust to colour roll-off when its thickness varies.

Figure 4 illustrates the calculated reflectance spectrum for a CR39 lens coated on both sides with the roll-off-resistant coating, as well as the reflectance spectrum when the coating thickness is reduced by 20%, as may be the case on the edge of a highly curved lens or in a deposition system that produced coatings of highly non-uniform thickness.

The lens displays relatively little luminance roll-off, with the luminous intensity of the reflection reducing from 1.3% to only 0.9% as the thickness of the coating is reduced by 20%. The lens changes from deep purple ( $h^* = 309^\circ$ ) through blue, to green ( $h^* = 164^\circ$ ). The change in hue is significant, yet despite

these changes in hue, the lens remains highly anti-reflective. Such a multi-coloured anti-reflection coating as would occur on a highly curved lens may be aesthetically pleasing.

**TABLE 4**

5      **Optical design for a balanced reflectance anti-reflection coating**

Layer	Thickness (nm)
CR39 lens element substrate	
SiO <sub>2</sub>	18
TiO <sub>2</sub> (n(500 nm) =2.15)	25.7
SiO <sub>2</sub>	20.1
TiO <sub>2</sub> (n(500 nm) =2.15)	118.7
Al <sub>2</sub> O <sub>3</sub> (n(500 nm) =1.64)	15.7
SiO <sub>2</sub>	90.7

### EXAMPLE 5

#### Balanced reflectance mirror coating

Table 5 shows the calculated optical designs for mirror coatings whose  
 10 reflectance is robust to colour roll-off when their thickness varies. The colour variations correspond to a thickness reduction of 20% and are clearly quite small.

Figure 5 illustrates the corresponding calculated reflectance spectra for  
 tinted CR39 lenses coated on the front surface with the roll-off-resistant coatings.  
 It can be seen that the resistance to colour roll-off has been achieved by designing  
 15 the coating to display a relatively flat reflectance in the near infra-red spectrum, as  
 opposed to a minimal infra-red reflectance as was the case for the roll-off-resistant  
 anti-reflection coatings. In addition, the spectra do not display sharp structure in  
 the visible wavelengths from 380-780 nm.

**TABLE 5****Optical designs for balanced reflectance mirror coatings**

Colour	Blue	Gold
Substrate	CR39	CR39
Layer 1	24.4 nm TiO <sub>2</sub>	14.8 nm TiO <sub>2</sub>
Layer 2	20 nm SiO <sub>2</sub>	100 nm SiO <sub>2</sub>
Luminance, Y	11.6%	2.3%
Hue, h*	270°	80°
Luminance change, $\Delta Y$	-2.4%	2.4%
Hue change, $\Delta h^*$	1°	15°
Colour difference, $\Delta E$	2.4	12

**CLAIMS**

1. A coated optical lens including  
a lens element; and  
a coating on a surface of the lens element exhibiting a substantially  
5 balanced reflectance from the centre to a radius proximate the edge of the lens  
element.
2. A coated optical lens according to claim 1 wherein the lens element  
includes a surface of high curvature upon which the balanced reflectance coating  
is deposited.
- 10 3. A coated optical lens according to claim 2 wherein the lens element is of  
generally ovaline shape and is located on the surface of a sphere whose radius of  
curvature corresponds to 11 D or above, a toroid where the horizontal radius of  
curvature corresponds to 11 D or above, or a surface where the radius of  
curvature changes across at least one section of the lens aperture.
- 15 4. A coated optical lens according to claim 1 wherein the coating additionally  
functions as an anti-reflective coating.
5. A coated optical lens according to claim 4 wherein the coating exhibits a  
substantially low photopic reflectance in the red to infrared wavelength range of  
approximately 620 to 880nm.
- 20 6. A coated optical lens according to claim 5 wherein the substantially low  
photopic reflectance is less than approximately 3%.
7. A coated optical lens according to claim 6 wherein the coating is a  
multicoloured, anti-reflective coating.
8. A coated optical lens according to claim 7 wherein the coating exhibits a  
25 reflected colour difference ( $\Delta E$ ) from the centre to a radius of approximately 20  
mm on the lens surface of greater than approximately 11 CMC colour difference

units, the colour difference being balanced by a complementary reduction in luminous intensity.

9. A coated optical lens according to claim 8 wherein the coating exhibits a reflected colour difference ( $\Delta E$ ) from the centre to a radius of approximately 20 mm on the lens surface of from approximately 11 to 20 CMC colour difference units.

10. A coated optical lens according to claim 6 wherein the coating exhibits a substantially uniform appearance from the centre to a radius proximate the edge of the lens element.

11. A coated optical lens according to claim 10 wherein, in use, the coating exhibits a reflected colour difference from the centre to a radius of approximately 20 mm on the lens surface of less than approximately 11 CMC colour difference units or less.

12. A coated optical lens according to claim 1 wherein the coating additionally functions as a reflective or mirror coating.

13. A coated optical lens according to claim 12 wherein the coating exhibits a substantially constant photopic reflectance in the red to infrared wavelength range of approximately 620 to 880nm.

14. A coated optical lens according to claim 13 wherein the coating exhibits a substantially uniform appearance from the centre to a radius proximate the edge of the lens element.

15. A coated optical lens according to claim 14 wherein, in use, the coating exhibits a reflected colour difference from the centre to a radius of approximately 20 mm on the lens surface of less than approximately 11 CMC colour difference units.

16. A coated optical lens according to claim 1 which coating includes a plurality



of layers, the thickness and/or number of which are selected to provide a substantially balanced reflectance in response to visual effects generated by variations in thickness of the coating.

17. A coated optical lens according to claim 16 including a plurality of layers of differing refractive index wherein the thickness and/or number of the respective layers are selected to balance the variation of any combination of reflectance lightness, hue and chroma.

18. A coated optical lens according to claim 17 where the layers of differing refractive index are formed from a dielectric material selected from one or more of  $\text{Al}_2\text{O}_3$ ,  $\text{BaTiO}_3$ ,  $\text{Bi}_2\text{O}_3$ ,  $\text{B}_2\text{O}_3$ ,  $\text{CeO}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{Ga}_2\text{O}_3$ ,  $\text{GeO}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{HfO}_2$ ,  $\text{In}_2\text{O}_3$ , Indium-tin oxide,  $\text{La}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{Nd}_2\text{O}_3$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{Pr}_2\text{O}_3$ ,  $\text{Sb}_2\text{O}_3$ ,  $\text{Sc}_2\text{O}_3$ ,  $\text{SiO}$ ,  $\text{SiO}_2$ ,  $\text{SnO}_2$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{TiO}$ ,  $\text{TiO}_2$ ,  $\text{TiO}_3$ ,  $\text{WO}_3$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{Yb}_2\text{O}_3$ ,  $\text{ZnO}$ ,  $\text{ZrO}_2$ ,  $\text{AlF}_3$ ,  $\text{BaF}_2$ ,  $\text{CaF}_2$ ,  $\text{CdF}_2$ ,  $\text{CeF}_3$ ,  $\text{HfF}_4$ ,  $\text{LaF}_3$ ,  $\text{LiF}$ ,  $\text{MgF}_2$ ,  $\text{NaF}$ ,  $\text{Na}_3\text{AlF}_6$ ,  $\text{Na}_5\text{Al}_3\text{F}_{14}$ ,  $\text{NdF}_3$ ,  $\text{PbF}_2$ ,  $\text{PrF}_3$ ,  $\text{SrF}_2$ ,  $\text{ThF}_4$ ,  $\text{ZrF}_4$ ,  $\text{Si}_3\text{N}_4$ ,  $\text{AlN}$ , diamond-like carbon, polymeric dielectric materials or doped dielectric materials.

19. A coated optical lens according to claim 18 wherein the lower index layers include a silica ( $\text{SiO}_2$ ) or magnesium fluoride ( $\text{MgF}_2$ ) material.

20. A coated optical lens according to claim 19 wherein the higher refractive index layer(s) exhibit a refractive index of approximately 2.0 or greater.

21. A coated optical lens according to claim 20 wherein the higher refractive index layer(s) include a titanium oxide ( $\text{TiO}_2$ ) layer or a combination of titanium oxide ( $\text{TiO}_2$ ) and praseodymium oxide ( $\text{Pr}_2\text{O}_3$ ).

22. A coated optical lens according to claim 21 including four to six alternating higher and lower refractive index layers of silica ( $\text{SiO}_2$ ) and a titanium oxide ( $\text{TiO}_2$ ) layer or a combination of titanium oxide ( $\text{TiO}_2$ ) and praseodymium oxide ( $\text{Pr}_2\text{O}_3$ ).

23. A coated optical lens according to claim 16 wherein the coating is formed of a plurality of dielectric and metallic layers wherein the thickness and/or number of

the respective layers are selected to balance the variation of any combination of reflected lightness, hue and chroma.

24. A coated optical lens according to claim 23 wherein the dielectric layer(s) is formed from a dielectric material selected from one or more of  $\text{Al}_2\text{O}_3$ ,  $\text{BaTiO}_3$ ,  $\text{Bi}_2\text{O}_3$ ,  $\text{B}_2\text{O}_3$ ,  $\text{CeO}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{Ga}_2\text{O}_3$ ,  $\text{GeO}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{HfO}_2$ ,  $\text{In}_2\text{O}_3$ , Indium-tin oxide,  $\text{La}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{Nd}_2\text{O}_3$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{Pr}_2\text{O}_3$ ,  $\text{Sb}_2\text{O}_3$ ,  $\text{Sc}_2\text{O}_3$ ,  $\text{SiO}$ ,  $\text{SiO}_2$ ,  $\text{SnO}_2$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{TiO}$ ,  $\text{TiO}_2$ ,  $\text{TiO}_3$ ,  $\text{WO}_3$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{Yb}_2\text{O}_3$ ,  $\text{ZnO}$ ,  $\text{ZrO}_2$ ,  $\text{AlF}_3$ ,  $\text{BaF}_2$ ,  $\text{CaF}_2$ ,  $\text{CdF}_2$ ,  $\text{CeF}_3$ ,  $\text{HfF}_4$ ,  $\text{LaF}_3$ ,  $\text{LiF}$ ,  $\text{MgF}_2$ ,  $\text{NaF}$ ,  $\text{Na}_3\text{AlF}_6$ ,  $\text{Na}_5\text{Al}_3\text{F}_{14}$ ,  $\text{NdF}_3$ ,  $\text{PbF}_2$ ,  $\text{PrF}_3$ ,  $\text{SrF}_2$ ,  $\text{ThF}_4$ ,  $\text{ZrF}_4$ ,  $\text{Si}_3\text{N}_4$ ,  $\text{AlN}$ , or diamond-like carbon, polymeric dielectric materials or doped dielectric materials; and
- 10 the metallic layer(s) is formed from a metallic material selected from the metals, metal oxides or metal nitrides of one or more of Aluminium (Al), Chromium (Cr), Niobium (Nb), Nickel (Ni), Palladium (Pd), Tin (Sn), Tantalum (Ta), Titanium (Ti), Tungsten (W), or Zirconium (Zr).
25. A coated optical lens according to claim 23, wherein the coating is a light absorbing asymmetric reflectance coating such that from the wearer's side of the lens element the coating is anti-reflective.
- 15
26. A multi-coated optical lens including  
a lens element,  
a coating on a surface of the lens element exhibiting a substantially  
20 balanced reflectance from the centre to a radius proximate the edge of the lens element; and  
one or more secondary coatings which provide a desirable optical and/or chemical and/or mechanical property to the optical article.
27. A multi-coated optical lens according to claim 26 wherein the secondary coating(s) overlays or underlays the balanced reflectance coating or is applied to a second surface of the lens element.
- 25
28. A multi-coated optical lens according to claim 26 wherein the secondary coating(s) is selected from one or more of an anti-reflective, abrasion-resistant, impact-resistant or hydrophobic coating.

29. A multi-coated optical lens including  
a lens element;  
a first coating on the front surface of the lens element; and  
a secondary coating on the back surface of the lens element; the first and  
5 second coatings in combination exhibiting a substantially balanced reflectance  
from the centre to a radius proximate the edge of the lens element.
30. A multi-coated optical lens according to Claim 29, wherein the secondary  
coating functions to reduce optical aberrations generated by the first coating.
31. A multi-coated optical lens according to Claim 30, wherein the secondary  
10 coating exhibits a difference in reflected brightness or hue relative to the first  
coating.
32. A multi-coated optical lens according to Claim 30, wherein the secondary  
coating exhibits a reflectance peak which is spectrally displaced with respect to a  
reflectance peak of the first coating.
- 15 33. A method for preparing a coated optical lens, which method includes  
providing  
a lens element; and  
a coating exhibiting a substantially balanced reflectance from the  
centre to a radius proximate the edge of the lens element; and  
20 depositing the coating on a surface of the lens element.
34. A method according to claim 33 wherein the lens element includes a  
surface of high curvature upon which the balanced reflectance coating is  
deposited.
- 25 35. A method according to claim 33 which method further includes  
providing  
a lens element,  
a high refractive index material, and

a low refractive index material;

depositing overlapping layers of high and low refractive index material on a surface of the lens element, wherein the thickness and/or number of the respective layers are selected to balance the variation of any combination of reflected lightness, hue and chroma.

36. A method according to claim 35 wherein the high and low refractive index materials, titanium oxide ( $\text{TiO}_2$ ) or praseodymium oxide/titanium dioxide ( $\text{Pr}_2\text{O}_3/\text{TiO}_2$ ) and silica ( $\text{SiO}_2$ ) respectively are deposited as alternating layers.

37. A method according to claim 36 wherein the balanced reflectance coating further provides an anti-reflective or a mirror effect.

38. A method according to claim 33, which method further includes providing

a lens element;

a dielectric material selected from one or more of  $\text{Al}_2\text{O}_3$ ,  $\text{BaTiO}_3$ ,  $\text{Bi}_2\text{O}_3$ ,  $\text{B}_2\text{O}_3$ ,  $\text{CeO}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{Ga}_2\text{O}_3$ ,  $\text{GeO}_2$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{HfO}_2$ ,  $\text{In}_2\text{O}_3$ , Indium-tin oxide,  $\text{La}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{Nd}_2\text{O}_3$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{Pr}_2\text{O}_3$ ,  $\text{Sb}_2\text{O}_3$ ,  $\text{Sc}_2\text{O}_3$ ,  $\text{SiO}$ ,  $\text{SiO}_2$ ,  $\text{SnO}_2$ ,  $\text{Ta}_2\text{O}_5$ ,  $\text{TiO}$ ,  $\text{TiO}_2$ ,  $\text{TiO}_3$ ,  $\text{WO}_3$ ,  $\text{Y}_2\text{O}_3$ ,  $\text{Yb}_2\text{O}_3$ ,  $\text{ZnO}$ ,  $\text{ZrO}_2$ ,  $\text{AlF}_3$ ,  $\text{BaF}_2$ ,  $\text{CaF}_2$ ,  $\text{CdF}_2$ ,  $\text{CeF}_3$ ,  $\text{HfF}_4$ ,  $\text{LaF}_3$ ,  $\text{LiF}$ ,  $\text{MgF}_2$ ,  $\text{NaF}$ ,  $\text{Na}_3\text{AlF}_6$ ,  $\text{Na}_5\text{Al}_3\text{F}_{14}$ ,  $\text{NdF}_3$ ,  $\text{PbF}_2$ ,  $\text{PrF}_3$ ,  $\text{SrF}_2$ ,  $\text{ThF}_4$ ,  $\text{ZrF}_4$ ,  $\text{Si}_3\text{N}_4$ ,  $\text{AlN}$ , diamond-like carbon, polymeric dielectric materials or doped dielectric materials; and

a metallic material selected from the metals, metal oxides or nitrides of one or more of Aluminium (Al), Chromium (Cr), Niobium (Nb), Nickel (Ni), Palladium (Pd), Tin (Sn), Tantalum (Ta), Titanium (Ti), Tungsten (W) or Zirconium (Zr)

depositing overlapping layers of dielectric and metallic material on a surface of the optical lens element, wherein the number and/or thickness of the respective layers are selected to balance the variation of any combination of reflected lightness, hue and chroma.

39. A method according to claim 38 wherein  
the dielectric material is magnesium fluoride ( $\text{MgF}_2$ ) or silica ( $\text{SiO}_2$ ); and  
the metallic material is Niobium (Nb) or Chromium (Cr).

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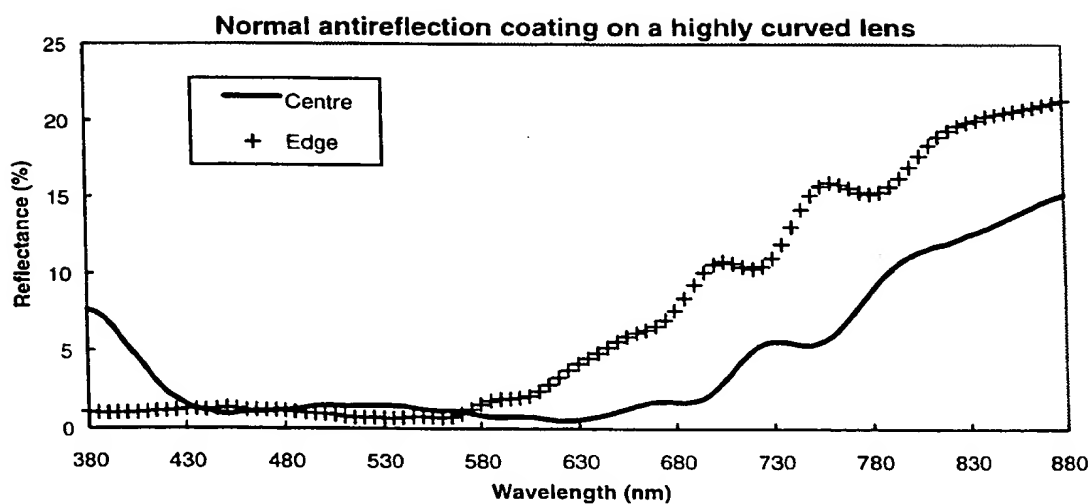


FIGURE 1

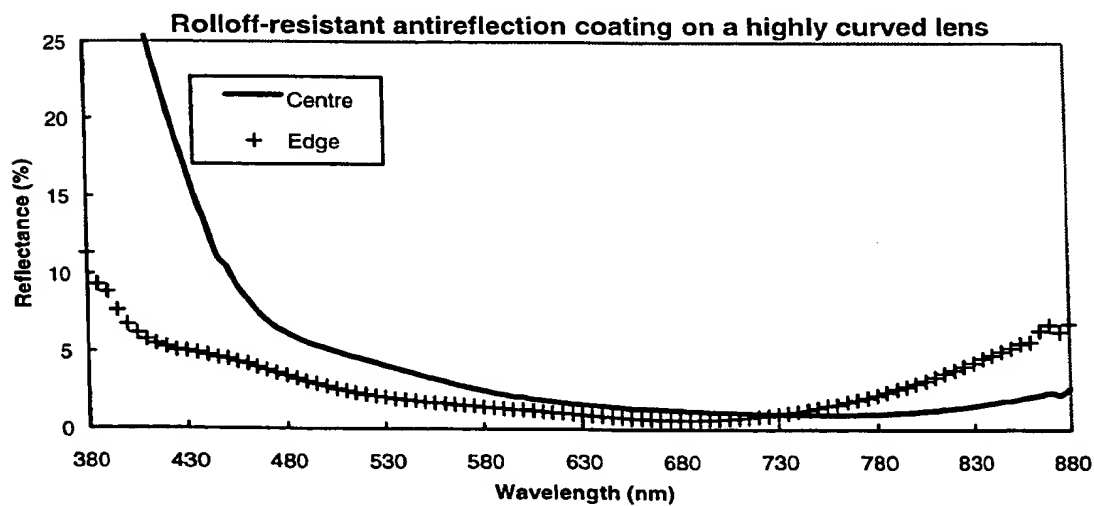


FIGURE 2

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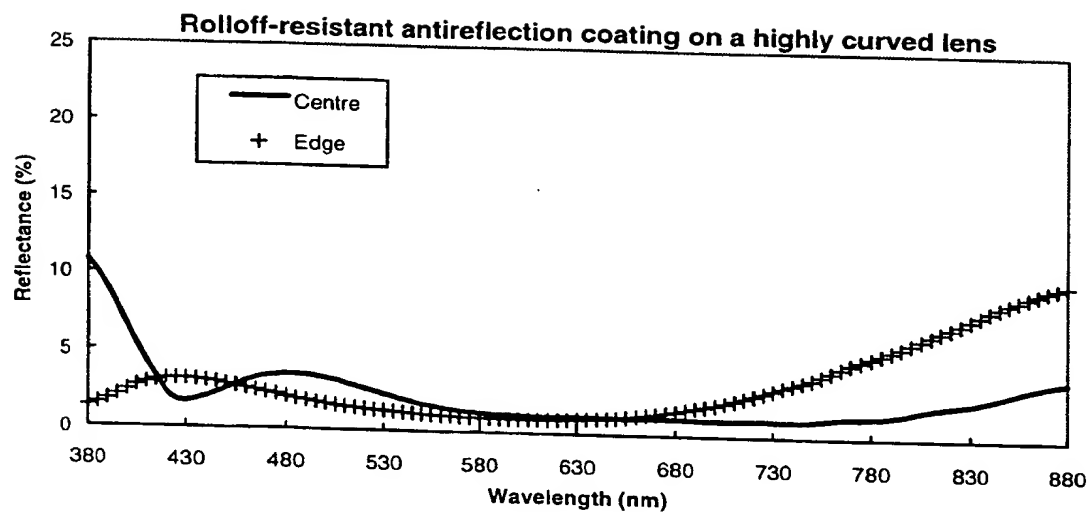


FIGURE 3

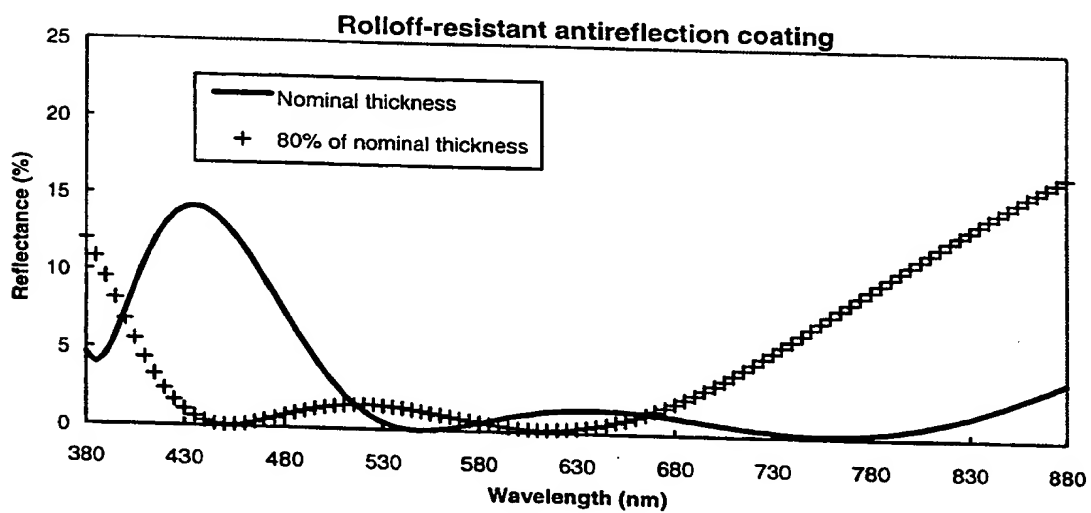
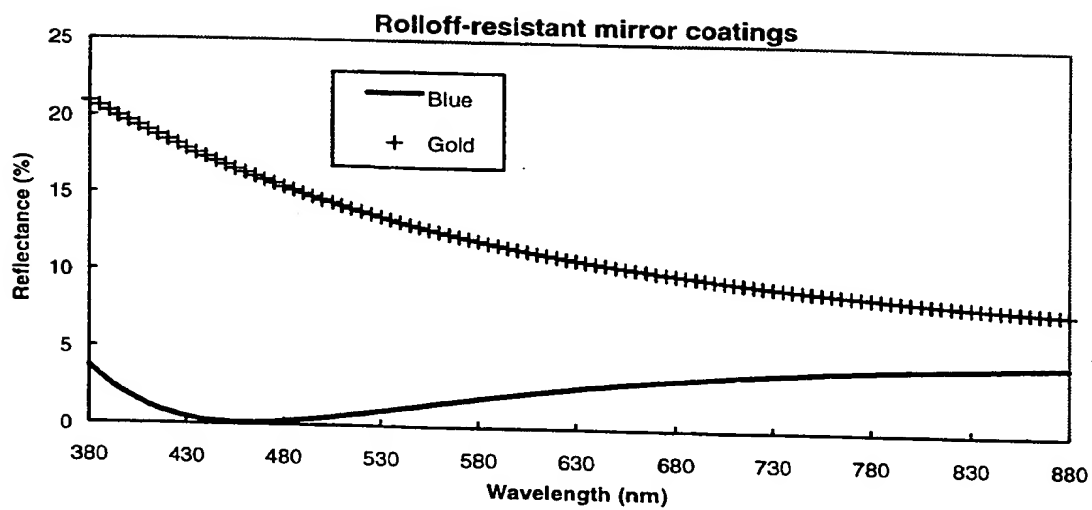


FIGURE 4

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**FIGURE 5**



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU 99/01029

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>																						
<i>Int. Cl.<sup>6</sup>:</i> G02B 1/11, 1/10																						
According to International Patent Classification (IPC) or to both national classification and IPC																						
<b>B. FIELDS SEARCHED</b>																						
Minimum documentation searched (classification system followed by classification symbols) <i>Int. Cl.<sup>6</sup>:</i> G02B 1/10, 1/11, 5/28, G02C 7/02, 7/10																						
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched																						
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) DWPI, JAPIO, IFIPAT: reflect+, antireflect+, anti (W) reflect+, mirror, refract+, curv+, convex, appearanc+, edg+, sun+, multi+																						
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>																						
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim N .																				
A	US 5719705 A (MACHOL) 17 February 1998 Table 1																					
A	US 5729323 A (ARDEN et al.) 17 March 1998 Tables 1 - 2																					
A	EP 791562 A1 (SAINT-GOBAIN VITRAGE) 27 August 1997 [& US 5952084 A (ANDERSON et al.) 14 September 1999] Examples 1 - 10																					
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C <input checked="" type="checkbox"/> See patent family annex																						
<p>* Special categories of cited documents:</p> <table border="0"> <tr> <td>"A"</td> <td>document defining the general state of the art which is not considered to be of particular relevance</td> <td>"T"</td> <td>later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"E"</td> <td>earlier application or patent but published on or after the international filing date</td> <td>"X"</td> <td>document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"L"</td> <td>document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"Y"</td> <td>document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"O"</td> <td>document referring to an oral disclosure, use, exhibition or other means</td> <td>"&amp;"</td> <td>document member of the same patent family</td> </tr> <tr> <td>"P"</td> <td>document published prior to the international filing date but later than the priority date claimed</td> <td></td> <td></td> </tr> </table>			"A"	document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family	"P"	document published prior to the international filing date but later than the priority date claimed		
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"P"	document published prior to the international filing date but later than the priority date claimed																					
Date of the actual completion of the international search 9 December 1999		Date of mailing of the international search report <b>21 DEC 1999</b>																				
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustalia.gov.au Facsimile No. (02) 6285 3929		Authorized officer  <b>RAJEEV DESHMUKH</b> Telephone No.: (02) 6283 2145																				

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU 99/01029

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5332618 A (AUSTIN) 26 July 1999 Tables 1 - 4	
A	US 5147125 A (AUSTIN) 15 September 1992 Tables 2 - 5	

## INTERNATIONAL SEARCH REPORT

### Information on patent family members

International application No.

PCT/AU 99/01029

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
US	5719705	AU	59347/96	EP	834092	WO	9641215
US	5729323	AU	29671/95	EP	772572	WO	9604216
EP	791562	FR	2745284	JP	9314746	US	5952084
END OF ANNEX							

**PATENT COOPERATION TREATY**  
**PCT**  
**INTERNATIONAL PRELIMINARY EXAMINATION REPORT**

(PCT Article 36 and Rule 70)

REC'D 03 AUG 2000

WIPO PCT

16

Applicant's or agent's file reference 40141788	<b>FOR FURTHER ACTION</b> See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).	
International application No. <b>PCT/AU99/01029</b>	International filing date ( <i>day/month/year</i> ) 19 November 1999	Priority Date ( <i>day/month/year</i> ) 30 November 1998
International Patent Classification (IPC) or national classification and IPC  <b>Int. Cl. <sup>7</sup> G02B 1/11, 1/10</b>		
Applicant <b>SOLA INTERNATIONAL HOLDINGS LTD et al</b>		

1.	This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.																								
2.	<p>This REPORT consists of a total of 5 sheets, including this cover sheet.</p> <p><input type="checkbox"/> This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).</p> <p>These annexes consist of a total of      sheet(s).</p>																								
3.	<p>This report contains indications relating to the following items:</p> <table style="width: 100%;"> <tr> <td style="width: 5%;">I</td> <td style="width: 5%; text-align: center;"><input checked="" type="checkbox"/></td> <td>Basis of the report</td> </tr> <tr> <td>II</td> <td style="text-align: center;"><input type="checkbox"/></td> <td>Priority</td> </tr> <tr> <td>III</td> <td style="text-align: center;"><input type="checkbox"/></td> <td>Non-establishment of opinion with regard to novelty, inventive step and industrial applicability</td> </tr> <tr> <td>IV</td> <td style="text-align: center;"><input type="checkbox"/></td> <td>Lack of unity of invention</td> </tr> <tr> <td>V</td> <td style="text-align: center;"><input checked="" type="checkbox"/></td> <td>Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement</td> </tr> <tr> <td>VI</td> <td style="text-align: center;"><input type="checkbox"/></td> <td>Certain documents cited</td> </tr> <tr> <td>VII</td> <td style="text-align: center;"><input type="checkbox"/></td> <td>Certain defects in the international application</td> </tr> <tr> <td>VIII</td> <td style="text-align: center;"><input checked="" type="checkbox"/></td> <td>Certain observations on the international application</td> </tr> </table>	I	<input checked="" type="checkbox"/>	Basis of the report	II	<input type="checkbox"/>	Priority	III	<input type="checkbox"/>	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability	IV	<input type="checkbox"/>	Lack of unity of invention	V	<input checked="" type="checkbox"/>	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement	VI	<input type="checkbox"/>	Certain documents cited	VII	<input type="checkbox"/>	Certain defects in the international application	VIII	<input checked="" type="checkbox"/>	Certain observations on the international application
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VIII	<input checked="" type="checkbox"/>	Certain observations on the international application																							

Date of submission of the demand 19 May 2000	Date of completion of the report 26 July 2000
Name and mailing address of the IPEA/AU  AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: <a href="mailto:pct@ipaustalia.gov.au">pct@ipaustalia.gov.au</a> Facsimile No. (02) 6285 3929	Authorized Officer  <b>RAJEEV DESHMUKH</b>  Telephone No. (02) 6283 2145

**I. Basis of the report****1. With regard to the elements of the international application:\***

- ☒ the international application as originally filed.
- ☐ the description,      pages , as originally filed,  
   pages , filed with the demand,  
   pages , received on      with the letter of
- ☐ the claims,      pages , as originally filed,  
   pages , as amended (together with any statement) under Article 19,  
   pages , filed with the demand,  
   pages , received on      with the letter of
- ☐ the drawings,      pages , as originally filed,  
   pages , filed with the demand,  
   pages , received on      with the letter of
- ☐ the sequence listing part of the description:  
   pages , as originally filed  
   pages , filed with the demand  
   pages , received on      with the letter of

**2. With regard to the language, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.**

These elements were available or furnished to this Authority in the following language which is:

- ☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

**3. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, was on the basis of the sequence listing:**

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

**4. ☐ The amendments have resulted in the cancellation of:**

- ☐ the description,      pages
- ☐ the claims,      Nos.
- ☐ the drawings,      sheets/fig.

**5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).\*\***

\* Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).

\*\* Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report

**V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement****1. Statement**

Novelty (N)	Claims 1 - 39	YES
	Claims	NO
Inventive step (IS)	Claims 1 - 39	YES
	Claims	NO
Industrial applicability (IA)	Claims 1 - 39	YES
	Claims	NO

**2. Citations and explanations (Rule 70.7)**

US 5719705 A (MACHOL)

EP 791562 A1 (SAINT-GOBAIN VITRAGE)

US 5332618 A (AUSTIN)

US 5147125 A (AUSTIN)

None of the citations discloses or (individually or in an obvious combination) suggests a coating on a surface of the lens element exhibiting a substantially balanced reflectance from the centre to a radius proximate the edge of the lens element. According to the description This coating reduces the phenomenon of colour rolloff without the need for planetary rotation apparatus. Therefore the claimed invention is novel, involves an inventive step and is industrially applicable.

**VIII. Certain observations on the international application**

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

1. According to the first written opinion, claim 1 is not clear because the terms "*the centre*" and "*the edge*" have no antecedents. The agent for the applicant has submitted that "the centre and edge of a coated optical lens would be well understood by a skilled addressee. A lens or a lens element clearly has a geometric centre and the lens element has an edge. There is no necessity, with respect, for these terms to have antecedents beyond the reference to the lens element itself."
2. According to the first written opinion, the independent claims are not clear because they seek to define the invention by a result to be achieved ("a substantially balanced reflectance") rather than by means of positive features which attain that result. The agent for the applicant has submitted that "the nature of the result to be achieved, namely a 'substantially balanced reflectance' is clearly defined in the body of the description and would be well understood by the skilled addressee. The means by which a substantially balanced reflectance is achieved, is clearly set out in the claim namely by placing a coating on the surface. The specification describes various coatings which will achieve a substantially balanced reflectance and, with respect, we cannot see that further is required."
3. According to the first written opinion, the claims are not clear with regard to the terms "*substantially*" and "*balanced* reflectance". Neither of the terms is clearly defined by the claims. The agent for the applicant has submitted that "again this objection is not understood. The term 'substantially balanced reflectance' has been defined in the body of the description and we do not see that further is required thereon."
4. According to the first written opinion, claims (at least) are not fully supported by the description because they do not refer to "highly curved substrates" (see page 1, lines 17 - 18 and 25 - 26 and page 3, lines 1 - 4) nor to "the thickness of the coating typically being greatest where the surface of the substrate is most normal to the incident flux of particles" (page 1, lines 21 - 26). The agent for the applicant has submitted that the item referred to by the examiner "is a preferment of the generality of the invention. For example the problem of colour roll-off is exacerbated by highly curved substrates but is not restricted thereto. The question of the thickness of the coating is described in the extract given by the examiner as merely typical and therefore a mere preferment."
5. According to the first written opinion, claims are not fully supported by the description because they do not define the absence of planetary rotation apparatus (page 2, lines 18 - 21). The agent for the applicant has submitted that "In relation to the planetary rotation technique, this, as is stated on page 2, was a simple proposal in the prior art which, as far as is known, has never been utilised presumably due to its complexity and expense. However the examiner, with respect, may have misinterpreted the nature of the present invention. The delivery of a substantially balanced reflectance is the product of the coating. And, for example, the thickness and numbers of the coating layers. The distribution of the coating across the surface is not apposite to the generation of a substantially balanced reflectance although it may assist."
6. According to the first written opinion, claims are not fully supported by the description because they are silent about the CMC colour variation of  $\Delta E_{\text{CMC}(2:1)}$  being approximately 3 or less (page 4, lines 6 - 7). The agent for the applicant has submitted that "In relation to the colour variation, with respect, the examiner appears to have misunderstood the nature of the discussion on page 4, lines 6-7. The reference to  $\Delta E$  of 3 or less this is a reference to a variation in individual lenses, not in relation to the lens itself."
7. According to the first written opinion, the claims are not fully supported by the description because they are silent about the low reflectance in the near infra-red spectrum (page 5, lines 19 - 20). The agent for the applicant has submitted that "this is clearly a preferment but equally the description makes it clear that even were this feature to be present it would not be sufficient for present purposes."

... continued

**Supplemental Box**

(To be used when the space in any of the preceding boxes is not sufficient)

**Continuation of Box VIII**

8. According to the first written opinion, the description is not clear because it does not give clear instructions (precise method steps) to a skilled person about how to go about designing and making the claimed lens. It is not enough to tell a skilled person to make a lens so that it has "a substantially balanced reflectance". The agent for the applicant has submitted that "this has been dealt with above. The description clearly discloses various coatings which will deliver the substantially balanced reflectance required by the skilled person. Some six examples are given and we respectfully submit that the skilled person would have no difficulty in duplicating the disclosure the subject of the present application."
9. According to the first written opinion, as a consequence of the above observation, the invention seems to have been claimed too broadly. The description gives only a few examples of the claimed lenses. However there is no teaching in the description about how to make a claimed lens which is not the same as the exemplified lenses. The agent for the applicant has submitted that "we cannot agree, with respect, with the examiner's conclusion. The skilled person is directed by the description to utilise multi-layer coatings typically of various high and low reflective index dielectric materials and vary the number and thickness of these coatings in order to achieve balanced anti-reflective coating proposed. Generally speaking, beyond that it is merely a question of colour. The skilled addressee may choose a preferred colour and make appropriate adjustments to the selection of refractive materials, the number of coating layers and their thickness to achieve the balanced reflectance coating required."



# PATENT COOPERATION TREATY

PCT

## NOTIFICATION OF ELECTION

(PCT Rule 61.2)

From the INTERNATIONAL BUREAU

To:

Assistant Commissioner for Patents  
United States Patent and Trademark  
Office  
Box PCT  
Washington, D.C. 20231  
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year)

27 July 2000 (27.07.00)

International application No.

PCT/AU99/01029

Applicant's or agent's file reference

40141788

International filing date (day/month/year)

19 November 1999 (19.11.99)

Priority date (day/month/year)

30 November 1998 (30.11.98)

Applicant

YIP, Brandon et al

1. The designated Office is hereby notified of its election made:

☒ in the demand filed with the International Preliminary Examining Authority on:

19 May 2000 (19.05.00)

☐ in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was

☐ was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO  
34, chemin des Colombettes  
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

Manu Berrod

Telephone No.: (41-22) 338.83.38

Form PCT/IB/331 (July 1992)

AU9901029